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Demystifying Over-the-Air Tests

Introduction to Over-the-Air Measurements, Chambers and Test Setup Calibration
测量、暗室和测试装置校准简介

Alexander Naehring, Fabricio Dourado
Rohde & Schwarz, Munich, Germany

Important Topics in OTA Testing

- Theoretical Background
  - Antennas and antenna parameters
  - Evaluating far-field conditions
- Testing Methodologies
  - Identify test parameters of interest
  - Measurement systems and positioners
  - Calibrating and evaluating OTA systems
  - Conducting accurate measurements

→ Very condensed overview, more detailed information in paper!

What is an Antenna?

e.g. coax, waveguide, …

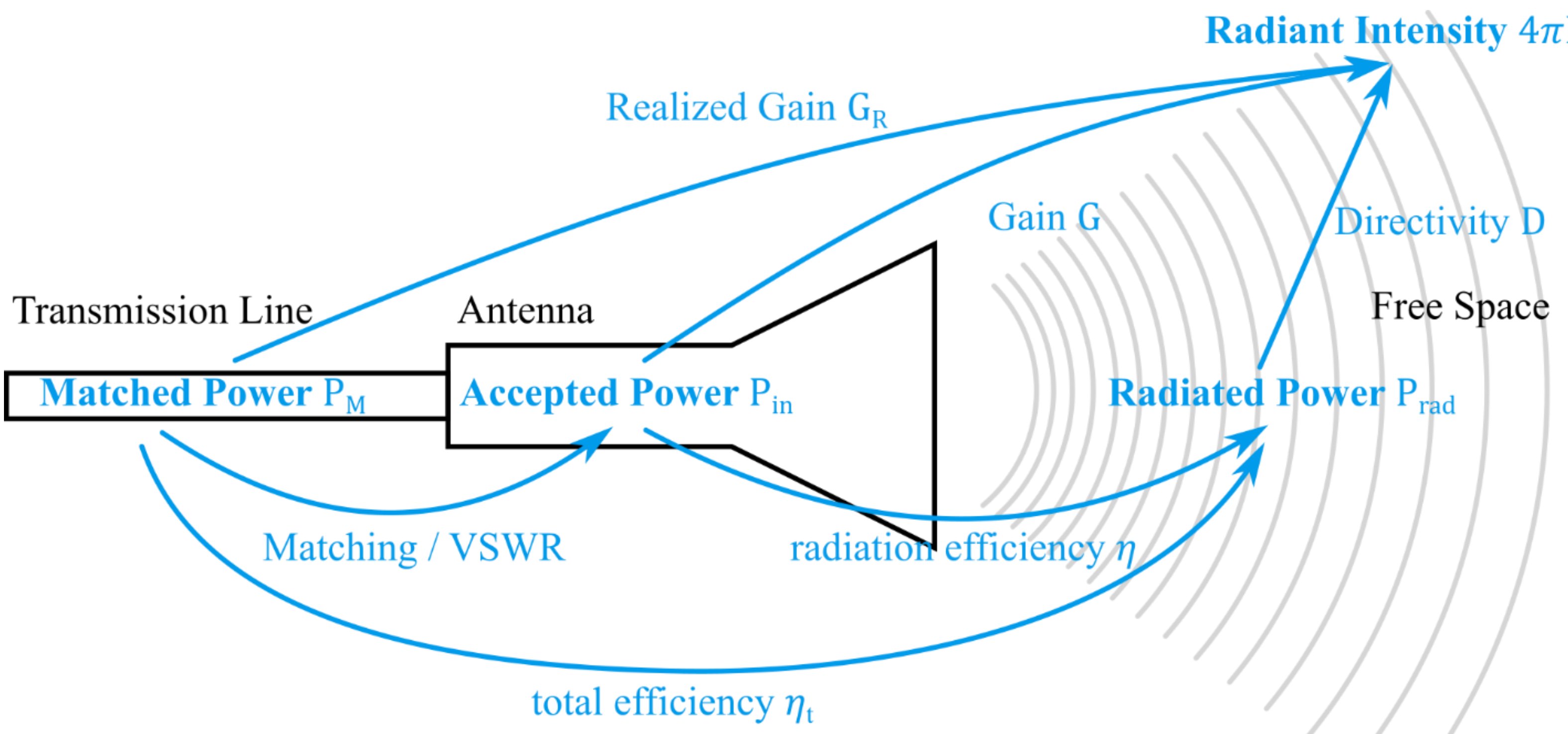
Component transforming
guided electromagnetic signals ⇔ electromagnetic waves *in **free space***

- Antennas are passive components and reciprocal (TX & RX)
- Can be combined with active components → Active Antenna

- The ideal antenna in theory: **isotropic radiator**
  - Radiates power without losses, equally in all directions
  - Used as base for FSPL[1] calculations and antenna parameter definition
  - Not possible in reality
    - Real antennas are *lossy* and *directed*

1) FSPL = free space path loss: $FSPL_{dB} = 20\log_{10}(d) + 20\log_{10}(f) - 147.55$

Antenna Parameters (1)



	Ideal Isotropic Radiator	Real Antenna
Power Levels	$P_M = P_{in} = P_{rad}$	$P_M > P_{in} > P_{rad}$
Efficiency	$\eta_t = \eta = 1$	$\eta_t < \eta < 1$
Directivity	$D = 1$	$D > 0\ dBi$

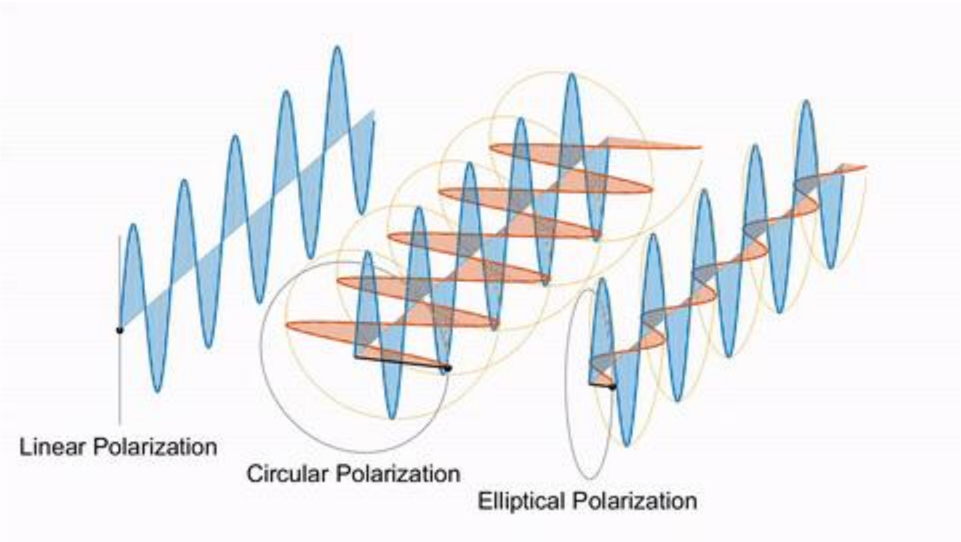
Antenna Parameters (2)

- **Realized Gain** is radiant intensity relative to intensity an isotropic radiator would produce with *matched power* P_M
- **Gain** is radiant intensity relative to intensity an isotropic radiator would produce with *accepted power* P_{in}
- **Directivity** is radiant intensity relative to intensity an ideal antenna would produce with *radiated power* P_{rad}
- **Effectively Isotropic Radiated Power (EIRP)** is the absolute power an isotropic radiator requires as input power to achieve the same power in a given direction

→ Referenced to isotropic radiator, and e.g. expressed in dBi
Parameters are frequency and direction dependent
If no direction given, peak value is assumed

Polarization

- **Polarization of wave:** orientation of E-field
- **Polarization of antenna:** polarization of transmitted wave
- **Types**: Elliptical, circular, linear

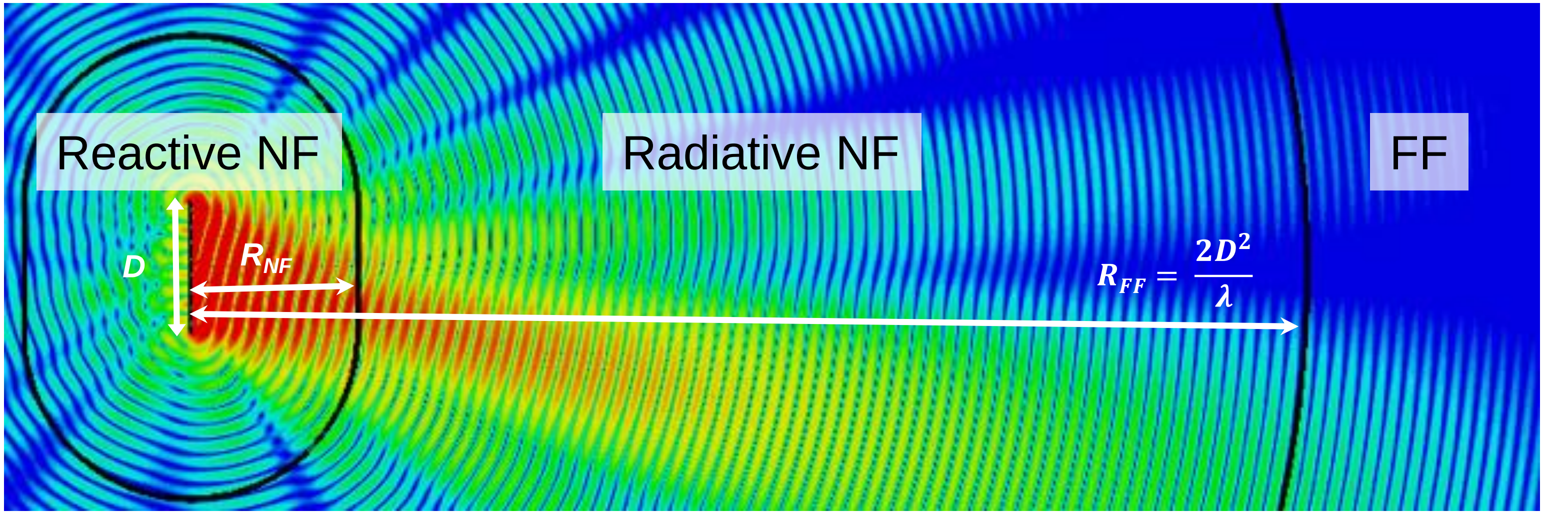


Animation of polarization components for linear, circular and elliptical polarization

Antenna must be **aligned** to receive full power
➔ polarization match / mismatch
Use two orthogonal polarizations for RX arbitrary polarizations

Near Field (NF) and Far Field (FF)

- All antenna parameters defined in far field
- **No** measurements in reactive near field



Scheme of NF and FF radiation

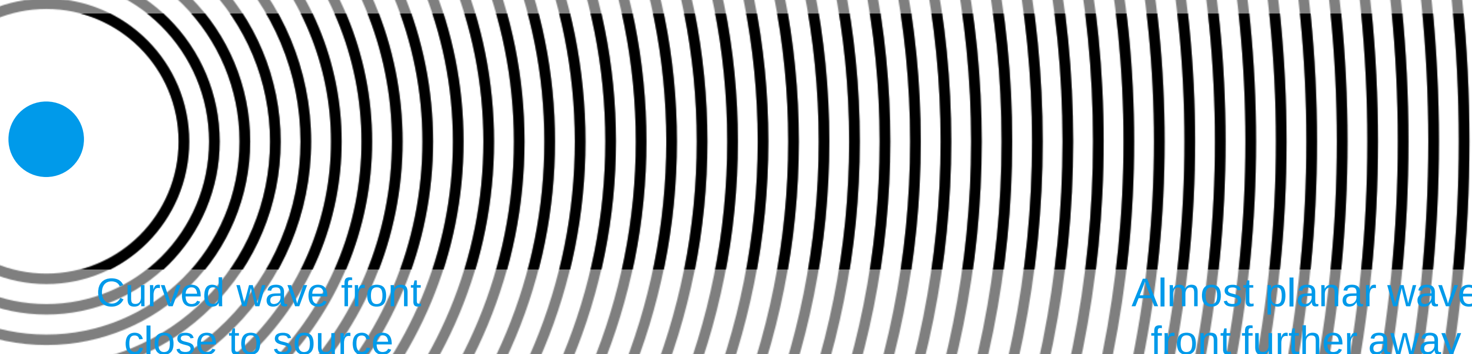
Measurements in "direct" far field and "indirect" far field, or in radiative near field with transformation

Far Field Requirement: Plane Waves

Far Field

defined by IEEE

In this region, the field has a predominantly plane-wave character



For a given aperture size D, the wave front will appear more planar the further away from the source

How to Achieve Plane Waves

- Fraunhofer Distance[1] $\mathrm{r_{FF}} = \frac{\boldsymbol{2D^2}}{\boldsymbol{\lambda}}$, and fulfill $r \gg D, r \gg \lambda$
  - Examples for FF distance at 3 and 30 GHz:
    - 30 cm device at 3 GHz: $r_{FF} = \frac{2\cdot(30cm)^2}{(10cm)} = \mathbf{1.8}\boldsymbol{m}$ typical chamber
    - 5 cm RF chip at 30 GHz: $r_{FF} = \frac{2\cdot(5cm)^2}{(10mm)} = \mathbf{0.5}\boldsymbol{m}$ small shielded box
    - 30 cm antenna array at 30 GHz: $r_{FF} = \frac{2\cdot(30cm)^2}{(10mm)} = \mathbf{18}\boldsymbol{m}$ very large room

Higher frequencies enable small antennas, but larger antenna arrays for beamforming increase far field distance significantly

- No reflections must disturb “free space propagation”

➔ Use of shielded anechoic chambers, boxes, or rooms

1) Fraunhofer distance is used for electrically large antennas, where $D > \lambda/2$

Quiet Zone

- For each chamber, can calculate maximum device size D from measurement distance r and frequency f
- Together with quality the chamber, measurement antenna, and absorbers, defines the size of “Quiet Zone” (QZ)

QZ is the zone in a chamber, where plane waves are assumed
QZ is the maximum DUT size measureable in FF conditions

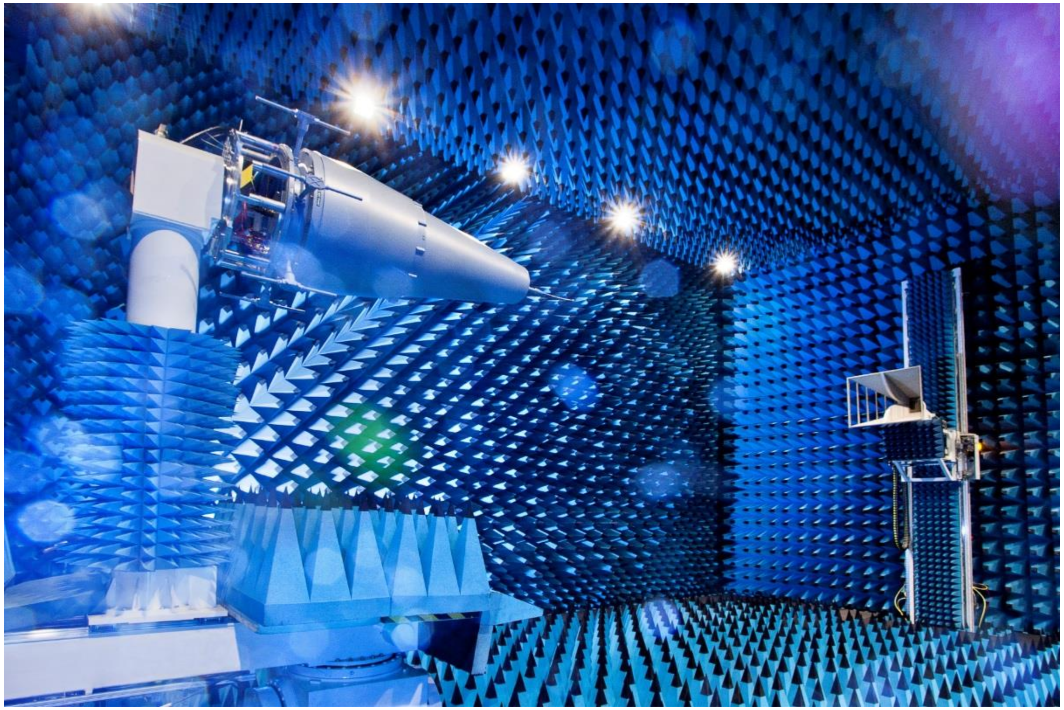
- If a DUT is larger then the QZ:
  - Fully anechoic chamber (FAC): assume NF measurement and transform to FF in post processing
  - Compact antenna test range (CATR) or similar: cannot measure DUT

What about Measuring?

- How to determine EIRP or gain of antenna?
  - Need calibrated system in anechoic environment
  - Far field conditions or near field measurement with transformation
  - find direction of peak power
  - keep environment and external parameters stable!

- How to conduct accurate link testing OTA?
  - Fixed positioning setup
  - anechoic environment optional/depending on surrounding
  - do not change alignment between DUT and probe antenna
  - keep external parameters stable!

Chamber Types (1)
Fully Anechoic Chamber



Antenna Measurement Chamber at
Rohde & Schwarz in Memmingen, Germany

- Measure direct far field with sufficient range
- Can measure radiating near field and transform
- Absorbers on all surfaces mitigate reflections

https://www.rohde-schwarz.com/product/ts8991

Chamber Types (2) Compact Antenna Test Range

- FF condition at distance $< r_{FF}$
- Chamber layout, surface roughness of reflector and feed antenna determine QZ quality
- Compared to FAC much smaller footprint for achieve same QZ size

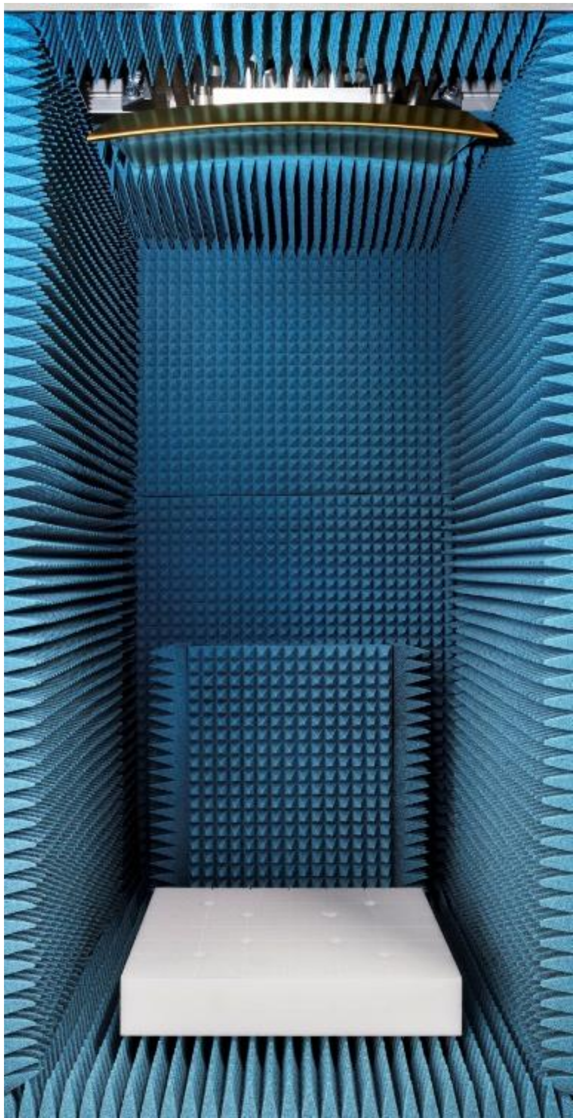
- Can not measure DUT > QZ
- Requires precise reflector alignment
- Requires combined axis positioner

Rohde & Schwarz ATS1800C Conformance Test System for UE mmWave OTA testing

https://www.rohde-schwarz.com/product/ats1800

Chamber Types (3)
Fixed Setups

- Chamber can be fitted with 3D or 2D positioners, or a fixed holder
- Smaller benchtop or rack chambers enable efficient
  - R&D testing
  - fast prototyping
  - regression testing of RFIC
  - etc…



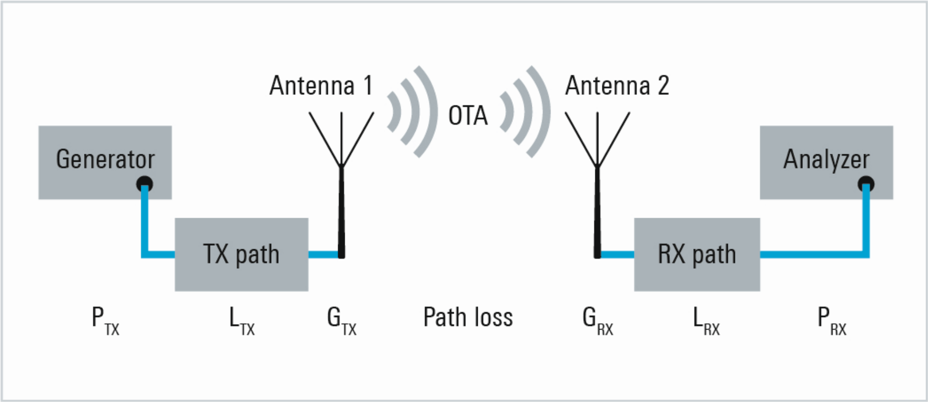
https://www.rohde-schwarz.com/product/ats800

Test System Calibration

- OTA Path Loss / System Calibration
  - Gain Transfer Method: Use a reference antenna with known gain
  - Three Antenna Method: Determine gain of three unknown AUTs
  - OTA power sensors: Measure field strength at air interface

- Always:
  - Take antenna polarization into account, use dual polarized probe, and calibrate both polarization paths
  - AUT phase center in rotation center (or defined location of test system)
  - Align antennas boresight (peak gain direction)

Gain Transfer Method



- Place reference antenna at AUT holder (phase cent = rot cent)
- Measure power difference f system: $L_{tot} = P_{TX} - P_{RX}$
- Remove known reference antenna gain: $L_{sys} = L_{tot} - G_{ref}$
- Now measure AUTs and remove the known system loss

Calibration only in single direction (peak beam direction)
but for both polarizations!

Test System Evaluation

- Positioning must be accurate
  - Mechanical alignment of positioning system
  - Placement of antenna on rotation center (or defined location of test system)
  - Polarization match to probe antenna
- Evaluate QZ (FF conditions in defined region in test chamber)
  - Measure amplitude and phase at different location in QZ
- Verify calibration and mechanical alignment:
  - Measure gain of known antenna, must be within limits
  - Compare results of polarizations, must be aligned for 90° rotations
  - Compare results at equivalent positions in test setup

A Few Words on OTA Test Types

- Antenna Characterization (active & passive)
  - Determine antenna parameters
  - Passive and active antennas with different focus
  - TRP, directivity, gain, EIRP, efficiency, pattern
- RFIC Tests and Similar
  - Testing front-ends and beamforming antennas, integrated circuits with focus on antenna parameters
  - Active components and/or signal processing
  - TRP, EIRP, sensitivity, beamforming, pattern
- Not antenna related OTA testing
  - Testing signal processing IC with focus on modulation quality, receiver performance, regression, etc.
  - EVM, sensitivity, etc… (no OTA focus)

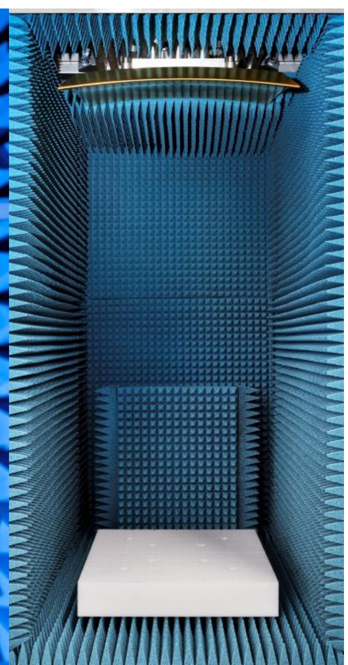
Anechoic chamber, 3D positioning system

Simplified, but controlled environment

R&S Measurement Solutions

- Turnkey solutions

  chamber, positioner system, measurement devices, antennas, accessories, automation software, training, etc…
- Different formfactors (benchtop, rack, portable, chamber, hall)
- From R&D to conformance

Thank You